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DISCLAIMER

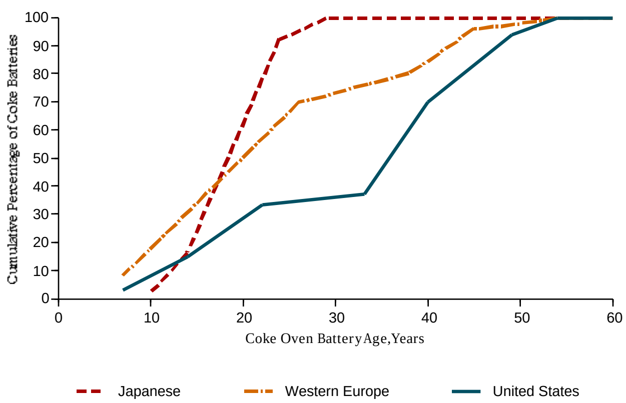
Geneva Steel, Centerior Energy Corp., and Air Products and Chemicals, Inc. currently hold no rights in or to the COREX® process or in or to the combined cycle power generation system and expressively disclaim any warranty or guarantee with respect to the information contained herein.

BACKGROUND

A growing coke shortage is impacting the U.S. ability to produce iron and steel. Driven by environmental concerns of the sixties, the government imposed increasingly stringent requirements upon the U.S. coking industry to substantially lower the level of airborne pollutants. The U.S. steel industry, subjected to the economics of the ‘70s and ‘80s and unable to justify the building of new coke units or the environmental modifications required to save its antiquated coking batteries, purchased foreign coke (**Figure 1**). The impact of this policy in the mid ‘90s has been a rapid depletion of the world's surplus in coke production. This depletion will be further impacted as the Clean Air Act Amendments of 1990 take effect.

Age of U.S. Coke Plants

FIG. 1



The U.S. steel industry, in order to maintain its basic iron production, is thus moving to lower coke requirements and to the cokeless or direct production of iron. The Department of Energy, in its Clean Coal Technology programs, has encouraged the move to new coal-based technology. The steel industry, in its search for alternative direct iron processes, has been limited to a single process, COREX®. The COREX® process, though offering commercial and environmental acceptance, produces a copious volume of offgas which must be effectively utilized to ensure an economical process. This volume, which normally exceeds the internal needs of a single steel company, offers a highly acceptable fuel for power generation. The utility companies seeking to offset future natural gas shortages are interested in this clean fuel.

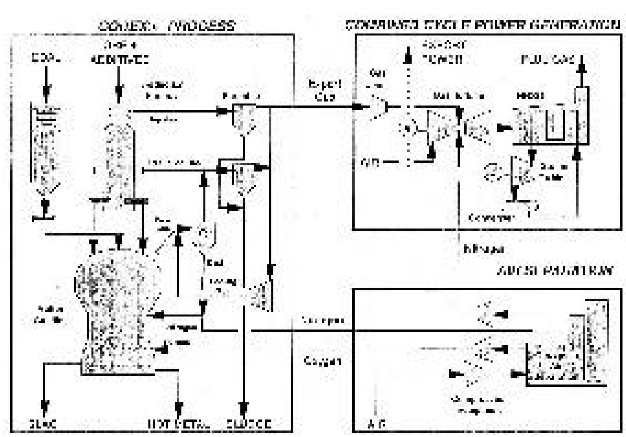
INTRODUCTION

The COREX® smelting process, when integrated with a combined cycle power generation facility (CCPG) and a cryogenic air separation unit (ASU), is an outstanding example of a new generation of environmentally compatible and highly energy efficient "Clean Coal" technologies. This combination of highly integrated electric power and hot-metal co-production, has been designated CPICOR™. "Clean Power from Integrated Coal/Ore Reduction." A consortium of leading companies who recognized the dilemmas of the U.S. steel and utilities industries. These companies jointly proposed to the U.S. Department of Energy a collaborative effort to commercially demonstrate the simultaneous production of iron and power by utilizing the COREX® export gases with an advanced U.S. combined cycle power generation unit (**Figure 2**). CPICOR further proposed to demonstrate optimum efficiency by combining the power generation and air separation units. The proposal was accepted for negotiation under Clean Coal V utilizing a 3,200 tons per day COREX® unit.

The consortium's selection of the COREX® process was based upon several factors. The U.S. urgently requires demonstration of direct iron production on a full commercial scale. The COREX®, as demonstrated by the operating unit at ISCOR and the unit under construction at Pohang, is the only process ready for upgrading to a production capacity suitable for the U.S. The Environmental Protection Agency requires an environmentally acceptable process. The COREX® process has fully demonstrated its compliance. The domestic steel

CPICOR Conceptual Flow Diagram

FIG. 2



industry is seeking economic operating incentives over the present coke plant/blast furnace route. The COREX® produces a lower cost hot metal. The utilities require a clean coal gas for commercial power generation. The COREX® produces gas flow rates and calorific levels more acceptable to power generation and with lower sulfur and NOx levels than all other processes.

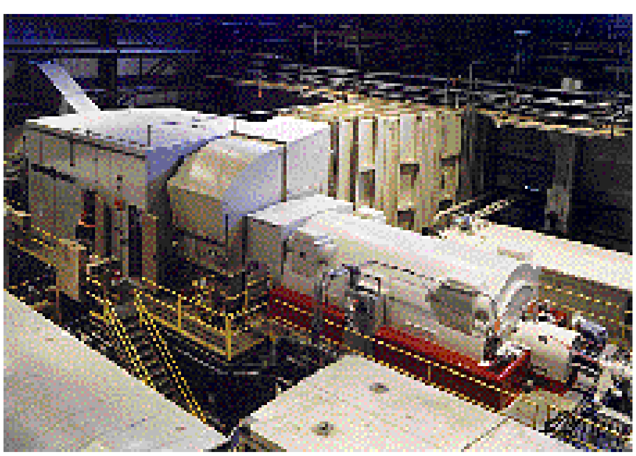
GLOBAL INTEGRATION

CPICOR is the integration of international innovations in power generation, direct ironmaking, and air separation that have reached a maturity for full scale commercialization. The U.S. Department of Energy and the major power generation equipment companies have spearheaded the development of the industrial gas turbine in the United States. From the first jet engines of the forties and through five decades of development, combined cycle power generation, using various energy sources, has developed to be the global answer for the nineties and beyond. Single combined cycle units can generate power levels to 220 megawatts (MW) with units under design for 350 MW (**Figure 3**). Coal gasification, as an energy source, has been successfully demonstrated at the Plaquemines facility in Louisiana and the Cool Water facility in California. These generation and gasification technologies will be the basis for CPICOR's high efficiency electrical power generation.

Development of direct ironmaking has been a recent challenge. Dominated by the simplicity and efficiency of the stolid blast furnace, direct ironmaking received secondary interest until the impact of environmental restrictions in the '70s and '80s. Focused specifically on coke oven emissions, environmental requirements have driven the cost of coke plants to a plateau unacceptable to U.S. and European industries. In response, the Germans and Austrians developed a direct ironmaking pilot plant in the '80s based on a concept of Korf Industries, which was eventually termed the COREX® process.[1] In the late 1980s, political pressure on South Africa resulted in the start up of the first small scale 330,000 tons per year COREX® unit (**Figure 4**). Since restarting in 1989, this plant at ISCOR has operated successfully on lump ores and non-coking coals. Encouraged by the success of the COREX® process and pressured by tightening environmental restrictions, the world's leading iron producers entered a belated race for direct ironmaking. The U.S. has under development the AISI direct ironmaking process (**Figure 5**), Japan the DIOS (**Figure 6**), Australia the HIsmelt (**Figure 7**), and Russia the ROMELT. Today, as evidenced by Korea's and India's selection of 770,000 tons per year COREX® processes, no other unit is yet ready for commercialization or offers any substantial benefit over COREX®/CPICOR for the United States.

The commercial production of oxygen in air separation units (ASU) is a well established technology (**Figure 8**). The process used for the first small 1.3 tons per day oxygen plant in the U.S. in the early 1900's was basically the same as that used in present 2,500 tons per day (TPD) installations. Over the history of the air separation industry, hundreds of commercial oxygen plants

Typical Gas Turbine Installation FIG. 3

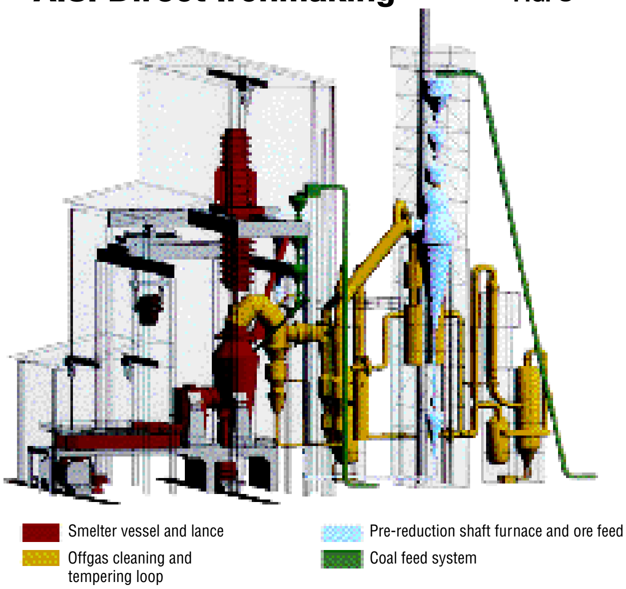


ISCOR COREX®

FIG. 4

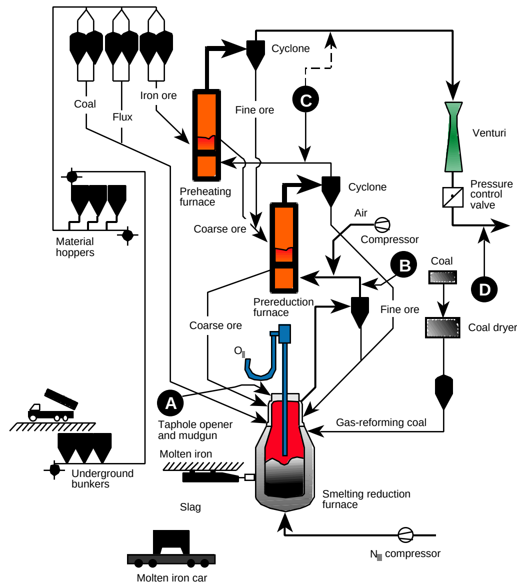
AISI Direct Ironmaking

FIG. 5



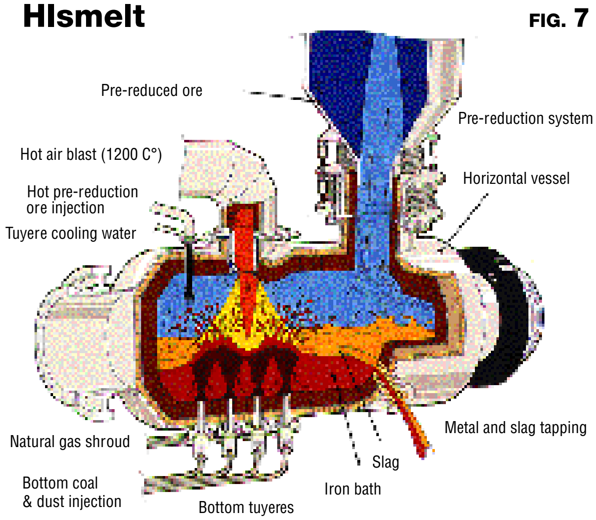
DIOS

FIG. 6



HIsmelt

FIG. 7



ASU Facility

FIG. 8

have been built, and presently more than 70,000 tons per day of oxygen capacity exists in the U.S. The ASU is proven, reliable, and highly efficient and will be integrated with the CCPG and COREX® within the CPICOR process. CPICOR will expand the U.S. coal base by including a wider range of coals for the simultaneous production of iron and power and will provide an integrated environmental solution for the economical revival of our steel, coal and power industries.

PROJECT OBJECTIVES

The project objectives are to demonstrate a scale up of the COREX® and its commercial integration with the advanced combined cycle power generation system. To date, the COREX® process has demonstrated the ability to produce 330,000 tons of hot metal per year on lump ore, with the generated gas used for inplant heating purposes. To be commercially viable in the U.S., the value of the generated gas must be optimized, such as by partial integration with power generation, and the

COREX® must be scaled up to a size compatible with modern blast furnace operation. The purpose of the CPICOR project is to demonstrate that COREX® technology can be integrated with combined cycle power generation. This is an efficient and environmentally attractive way to utilize the COREX® export gas. The 3,300 net tons per day COREX® unit selected for the CPICOR project will produce 1,160,000 tons of hot metal per year to further demonstrate a 3:1 scale-up over the existing ISCOR facility, a 3:2 scale-up over POSCO's planned Pohang facility in Korea, and a viable size for U.S. operations.

PROJECT TEAM

The project team is comprised of: Centerior Energy Corp.; Air Products and Chemicals, Inc.; and Geneva Steel. Together with their principal subcontractors, Deutsche Voest Alpine Industrialanlagenbau (DVAI) and Voest Alpine Industialanlagenbau (VAI), this team is well qualified to effectively execute all phases of the CPICOR demonstration. The CPICOR project will be managed through a joint-venture entity of the partners, CPICOR Management Company, who have executed the cooperative agreement with the DOE.

DVAI, the developer of the COREX® process, will work with Geneva Steel to design and construct CPICOR's 3,300 TPD COREX® facility. Geneva Steel will provide the infrastructure of their fully integrated steel plant in Vineyard, Utah, and consume the hot metal product (**Figure 9**). Centerior Energy will bring power generation expertise. Air Products will supply its extensive project experience and technology leadership in innovative air separation plants and power generation systems.

TECHNOLOGY DESCRIPTION

The backbone of the CPICOR project is the innovative process known as COREX® in which molten iron is produced by continuous reduction and smelting of iron ore (**Figure 10**). The most innovative feature of this process is the segregation of the iron reduction and smelting into two separate reactors. This allows direct injection of coal into the high temperature melter/gasifier which thermally cracks the coal volatiles as they are released. The process is thus independent of coke. The two reactors are:

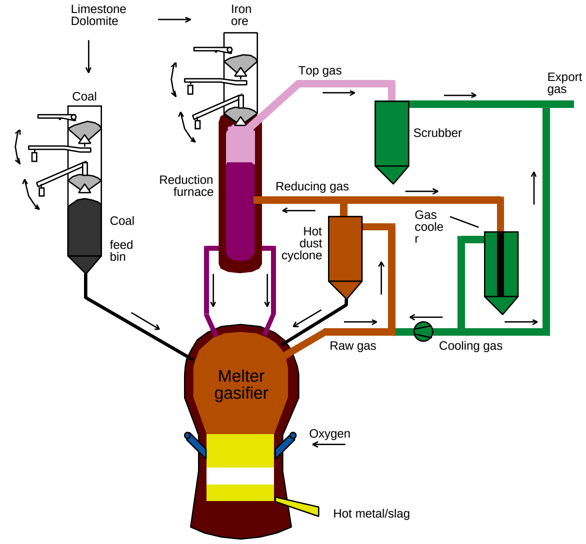
1) A **reduction shaft furnace** for reduction of lump ores, pellets, or sinter.

2) A **melter/gasifier** into which a wide variety of coals can be fed directly to produce the heat needed for smelting and to generate the reducing gases required for reducing the iron ore.

The coke oven plant with its related emissions is eliminated, and the coal gases normally required for coking can be more efficiently utilized for generating power. Hence, in addition to hot metal production, significant volumes of a clean, low-calorific value gas (175-230 BTU/SCF) are continuously generated from the COREX® process. This gas then serves as the fuel for a combined cycle power generation system.

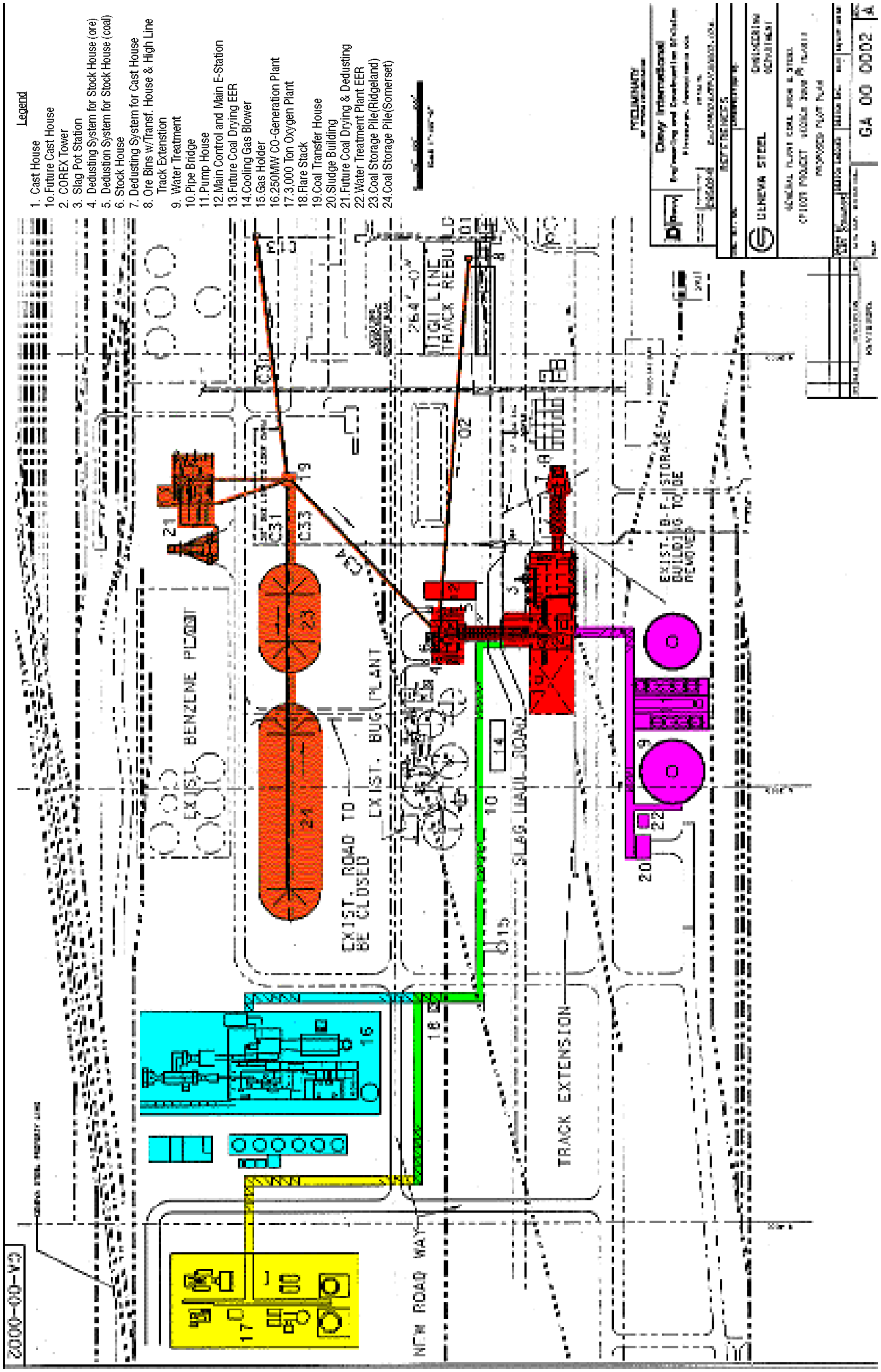
The COREX® flow diagram shows coal fed directly into the COREX® melter/gasifier. The coal, a blend of Western and Eastern coals, is devolatilized and gasified with oxygen to generate a reducing gas and sufficient heat to smelt hot metal. The process will normally use some 3,570 tons of coal and 2,700 tons of oxygen to produce 3,300 tons of hot metal per day. The high temperatures (1,800°F- 2,000°F) in the melter/gasifier result in the thermal dissociation of the coal volatiles, leaving only small amounts of

COREX® Process Flow **FIG. 10**



Site Location

FIG. 9



CH_4 in the reducing gas. The gas exits the melter/gasifier and passes through the dust separation cyclone before it is cooled to 1,550˚F and transferred into the reduction shaft furnace. The reduction furnace is fed 5,180 TPD of iron ore and pellets and 953 TPD of raw fluxes. The charge is reduced or calcined by the ascending reducing gas. During the ascent, the sulfur contained in the gas reacts with the reduced iron and the calcined lime and dolomite. The reduced iron and the calcined fluxes are fed by water-cooled screws into the melter/gasifier. In the melter/gasifier, the reduced iron is melted by heat generated from the partial oxidation of the coal. The sulfur released during the smelting process is chemically captured in a calcium-rich, basic slag. The hot metal and slag are tapped periodically from the furnace hearth. The molten metal is sent directly to the steel mill for processing and the tapped slag (1,354 TPD) is recovered and used in the same manner as blast furnace slag.

The spent reducing gas (or top gas) leaves the reduction shaft essentially desulfurized and is quenched and cleaned through a series of wet scrubbers equipped with cyclonic separators. The cleaned export gas (1,790 MMBTU/hr) is delivered to the CCPG facility where it is compressed, mixed with air and nitrogen, and burned in a gas turbine/generator system. Process steam is generated in a heat recovery steam generator (HRSG) by extraction of heat from hot turbine exhaust gases and the combustion of surplus export gas. The steam produced in the HRSG drives an electric generator. This combination results in a total of 250 MW to 330 MW of generated power depending on the type of gas turbine used. Alternatively, a portion of the COREX® gas can be combusted within Geneva's plant for such processes as soaking pits, reheating furnaces, etc., with the major portion being used for combined cycle power generation. This results in 241 MW of generated electric power.

In addition to demonstrating the use of COREX® gas in a CCPG unit, another key innovative feature of the CPICOR design is the integration of the gas turbine with the ASU. A stream of air is extracted at the gas turbine axial compressor discharge to partially supply the ASU process air requirements. The ASU is designed to produce nitrogen and 3,000 TPD of high purity oxygen for the COREX® process. A portion of the nitrogen produced by the ASU is returned to the gas turbine, mixed with the compressed hot gas stream, and used to boost power output.

INHERENT ADVANTAGES OF CPICOR

CPICOR technology, by virtue of its integral co-production of hot metal and power, offers a number of distinct technical and economic advantages over the competing commercial technology. The conventional method of producing hot metal from ore and coal involves two separate processes:

1) **Cokemaking** — Coal is heated to drive off volatile matter and produce "coke" to be used as both fuel and reducing agent in a smelting operation.

2) **Blast furnace smelting** — Ore, coke, limestone, and hot air are charged to reduce and smelt the ore to produce molten iron.

Approximately 30% of the coke oven gas produced during cokemaking is used to provide heat for the cokemaking operation. The excess gas is typically sent to a utility steam boiler where it is mixed with the surplus off-gas from the blast furnace to generate power. At comparable hot metal production rates, this technology generates only about one-fifth the power produced by CPICOR technology.

Highly Efficient Use of Coal

The energy efficiency of the CPICOR technology is over 30% greater than the competing commercial technology when considering only the effective production of hot metal and electric power. The higher efficiency of the CPICOR technology is due to the more effective use of the sensible heat and volatile matter than the coke-making/blast furnace process. In addition, the CCPG achieves energy efficiencies in the 50% range compared to a maximum of 34% with conventional coal-based power systems equipped with flue gas desulfurization.

Dramatic Reduction in Emissions

CPICOR technology is less complex and environmentally superior to conventional processes. All criteria air pollutants, particularly the acid rain and PM_{10} precursors, SO_x and NO_x, are reduced by more than 85%. This reduction is due largely to the desulfurizing capability of the COREX® process, efficient control systems within the CCPG facility, and the use of oxygen in place of air in the COREX® process. The gaseous emissions from the CPICOR plant, resulting from the combustion of air and export gas in the gas turbine, are effectively controlled.

As the air toxics provisions of the Clean Air Act Amendments of 1990 take effect, the steel industry faces a serious challenge of reducing coke plant emissions. CPICOR meets this challenge because it eliminates the need for cokemaking and the associated problems of controlling fugitive emissions. The COREX® process releases no air toxics from the high temperature gasifier to the environment, and most trace elements are captured in the slag. There is no negative impact from the discharge of solids or waste waters from the CPICOR plant since all discharges are non-hazardous. The predominant solid by-product of the COREX® process is a usable slag which is very similar to blast furnace slag and can be sold as construction ballast.

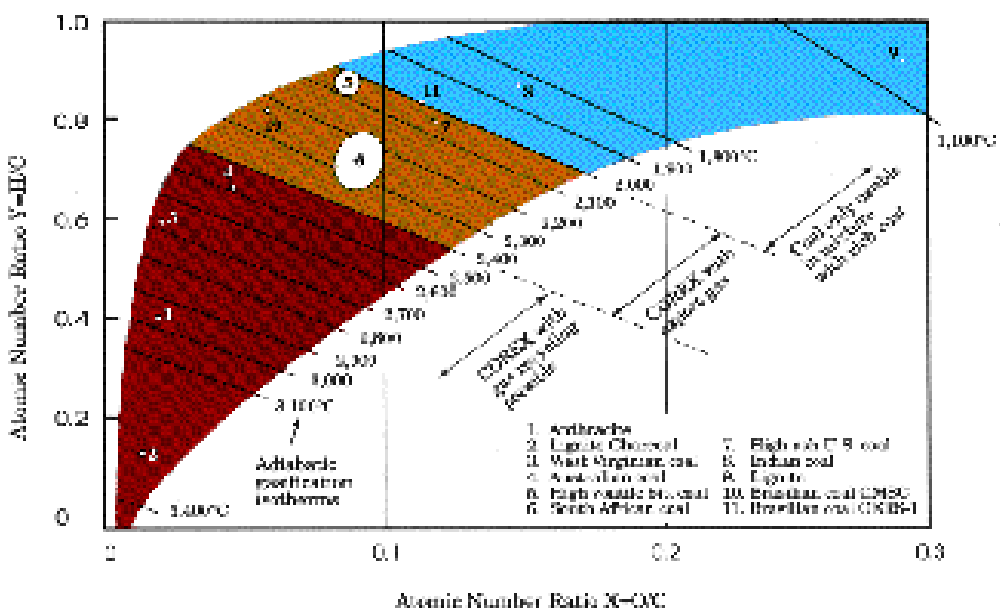
Intrinsic Desulfurization Capability

CPICOR technology has a distinct environmental advantage over conventional coal fired power generation units. Conventional coal fired units require an expensive flue gas desulfurization to clean the offgas to acceptable environmental levels. This flue gas cleanup is totally eliminated in the CPICOR process. The limestone and/or dolomite charged to the COREX® is extremely effective in scavenging the sulfur. The sulfur is removed almost totally as Ca(Mg)S with a small portion entering the iron as FeS and a fraction less than 50 ppm as H_2S or COS in the offgas.

Operational Flexibility with a Range of Coals

Unlike blast furnace technology, which requires the use of coke produced from coking coals, the COREX® process operates effectively with a wide variety of coals fed directly into the process (**Figure 11**). Since coke is produced from a narrow range of coal types with specific properties, the vast majority of the United States coal reserves cannot be utilized in conventional ironmaking. The spectrum of available coal reserves for domestic ironmaking is considerably enhanced by CPICOR. The COREX® process effectively operates over a broad range of coal qualities: volatile matter up to 35%, ash up to 25%, and sulfur up to 1.5%. Even very high sulfur coals (>1.5%) can be used effectively in the COREX® process provided they are blended appropriately with low sulfur coals.

Reference Chart for COREX® Coals **FIG. 11**



Competitive Co-Product Economics

Current commercial technology uses stand-alone process units to produce hot metal, supply industrial gases and co-produce electric power. As a result, capital costs are high, and the opportunity to integrate various process flows and heat sources among the processes is lost. In contrast, the CPICOR design is based on achieving capital, operating, and energy benefits by integrating the processes without sacrificing the flexibility for commercial operation and the reliability of power or hot metal production.

FEASIBILITY OF CCPG INTEGRATION

Although this is the first CCPG application to be fueled with COREX® export gas, the proposed design is based on proven technology. Similarly sized and larger CCPG facilities have been designed and are currently in reliable operation today with 94% to 97% availability. The steam pressure levels selected for the CPICOR design are typical of those which have been used in power generation facilities for years. The proposed gas turbine system is a proven, reliable design with a considerable number of the candidate models currently in operation. There are many heat recovery steam generator (HRSG) units of similar design and size in operating CCPG installations. Many steam turbine/electric generator sets of the type and capacity proposed for CPICOR currently exist in electric power generation facilities and have been in operation for years. All other major equipment items for the CCPG facility are likewise based on existing technology and similarly sized units (**Figure 12**).

The fueling of a CCPG system gas turbine with low-BTU gas produced by the COREX® process is unique. However, fueling gas turbines with medium and low-BTU fuel is a technology which exists commercially and is being studied, developed, and optimized by the gas turbine manufacturers. Consuming COREX® export gas in a turbine presents some technical challenges not encountered with fired boiler combustion cycles. Particulates greater than 5 microns and alkali metals can lead to turbine blade erosion. In combination with H_2S and SO_2, these materials can lead to hot metal corrosion of the combustor and inlet transition duct as well as blading of the turbine section. These potential problems are addressed by adequate scrubbing and filtration of the export gas in the CPICOR design. The use of proven and reliable wet scrubber technology will provide over 99.5% dust removal. Performance data from the ISCOR operation shows the COREX® export gas has contaminant levels generally within the gas turbine manufacturers' maximum specifications.

Combined Cycle Statistics

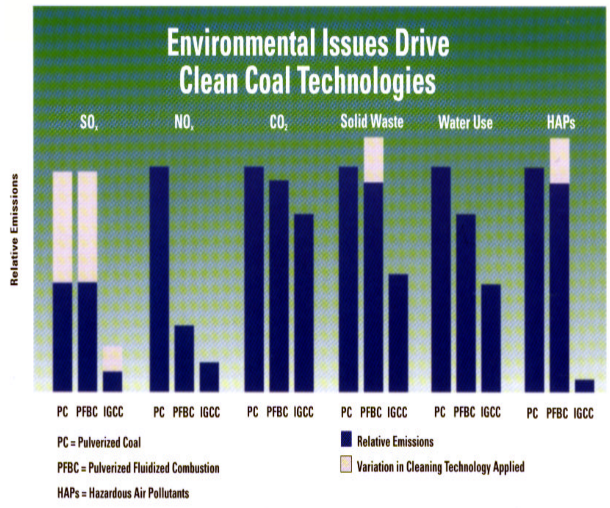
FIG. 12

Installed Combined Cycle Units

Installed Capacity (U.S.)	Over 66,000 megawatts
Operation Hours (U.S.)	Over 77 million hours
Power Range	Up to 350 MW per unit
Thermal Efficiencies	Up to 54+%
Availability	90 to 97%
Heat Rates	9000 to 6200 BTU/KWH

Coal Gasification Units

Plaquemine	two 104 MW units installed 1974
Cool Water	one 120 MW unit installed 1984
Environmental	1/10 of coal fired units



Considerable advancements have also been made in gas turbine hot section metal coatings. Cooling technologies have been developed to reduce the erosion and corrosion effects of firing offgases from processes such as COREX®. Westinghouse, Mitsubishi Heavy Industries (MHI), Siemens, ABB, General Electric, and European Gas Turbines (Ruston) all report capabilities to accept the COREX® export gas with only minor modifications to the gas turbine designs.

Operation of the gas turbine with COREX® export gas and integration with the ASU pose some unique control requirements. Nevertheless, Air Products has studied the requirements of gas turbine and ASU integration in depth and is currently demonstrating ASU-gas turbine integration, analogous to CPICOR's design, at DEMKOLEC's Integrated Gasification Combined Cycle (IGCC) facility in Buggenum, Netherlands.

DEMONSTRATION SITE

The CPICOR demonstration plant will be constructed at Geneva Steel's plant located in Vineyard, Utah. At that site, Geneva owns and operates a fully integrated steelmaking facility.

The site will take advantage of existing infrastructure to use the generated electricity at the site and transmit the surplus to the local power grid (**Figure 9**). All of the hot metal will be consumed in the steel plant. Raw materials for the demonstration plant, coal, iron ore and limestone, will be supplied by existing transportation, storage, and processing infrastructure on the site.

PROJECT SCHEDULE AND MILESTONES

The project is scheduled to commence upon the signing of the cooperative agreement with the DOE and to be completed following a multiple-phase program (**Figure 13**).

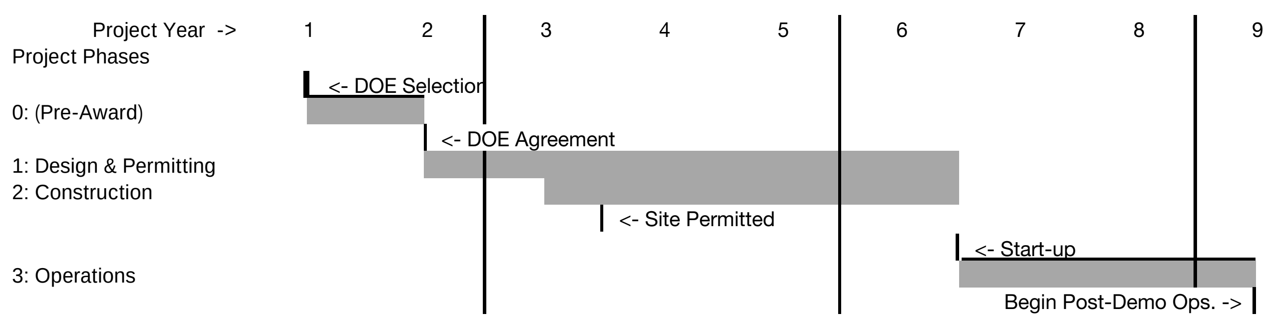
Demonstration Operating Plan

CPICOR's main objective is to demonstrate the economic, environmental, and operational aspects of a commercial-scale integrated facility and to qualify the plant using a variety of U.S. coals. CPICOR will be operated in most modes expected to be encountered in commercial applications, with the following goals:

- Establishing steady and reliable operation which compliments and enhances steel mill operations.
- Collecting performance data at various loads and conditions to assess process sensitivities, optimum conditions, and limits of sustainable operation.
- Verifying suitability of equipment and materials.
- Assessing the effect of applying new information to design and cost estimates for future commercial plants of this type.
- Testing different U.S. bituminous coals and blends to observe the effects of volatile matter, sulfur, and ash variation on performance and equipment.

To achieve these goals, a 29 month program

Project Time Line **FIG. 13**



consisting of four commercial operating periods is planned:

1. Base Coal Line-Out (4 months)
2. Steady-State Integration and Optimization (9 months)
3. Coal Quality Testing (14 months)
4. Maximum Capacity Testing (2 months)

Once the CPICOR demonstration plant is operational, it will be run as a commercial facility, producing and selling products. It will become a major source of hot metal and a net producer of electric power.

The plant will be run by the operating staffs of Geneva and Air Products. Geneva will operate the COREX® facility and will monitor all CPICOR-related systems as part of its normal steel mill functions. Air Products will operate the CCPG and ASU facilities. Each partner will supply engineering, plant staff, labor, materials, routine and major maintenance, home office support, subcontracts, and all other services needed. In addition, DVAI will provide continuous on-site support, advice, and evaluation on the technical aspects of the COREX® operation.

Post Demonstration Phase

Upon completion of the DOE program, it is anticipated that the CPICOR plant will continue to operate as a commercial facility for at least 20 years, supplying Geneva's hot metal and power.

COMMERCIAL OUTLOOK

CPICOR is intended to replace commercial coke oven/blast furnace technology in the production of hot metal for use in steelmaking. The best candidates for utilizing CPICOR technology are existing integrated steel plants with blast furnaces and coke ovens nearing the end of their useful lives and located where the local electric utility requires additional capacity. While commercialization of the COREX® process is driven primarily by the need for an environmentally sound source of hot metal for the steel industry, the production of electric power from the COREX® export gas is key to the economic competitiveness of the technology. Thus, commercialization will be facilitated by the ability of this project to obtain an attractive price for the power created by the plant.

Conventional coke oven/blast furnace technology is too expensive to be utilized as replacement units or to expand domestic ironmaking capacity. Recent studies [2, 3, 4] conclude that no new coke batteries will be built in the United States. Of the existing 79 coke oven batteries, 40 are thirty years of age or older and are due for either replacement or major rebuilds.

As a consequence of the Clean Air Act Amendments of 1990, the emissions from existing coke ovens must be reduced substantially over the next several years. It has been estimated that the total capital investment for rebuilding or replacing current capacity could be in the range of $4 to $6 billion. The capital cost of coke ovens is about $166 per ton of equivalent hot metal capacity. Coupled to the cost of a blast furnace rebuild at $155 per ton equivalent hot metal capacity, the investment in a new COREX® facility at approximately $255 per ton compares favorably on a capital basis.

If the iron and steel industry is to continue to produce liquid iron in the form of hot metal, a new technology must be developed and installed. Future competition to COREX® is likely to come from the new direct ironmaking processes being developed in both Japan (the DIOS process, **Figure 5**) and in the U.S. (the AISI process, **Figure 6**). Both of these processes produce iron and a lower calorific value export gas directly from iron ore and coal. However, the development of the COREX® technology is 8 to 12 years ahead of these other processes. Consequently, COREX®/CPICOR should become the technology of choice as domestic ironmaking capacity declines due to severe limitations in global coke supply.

RATIONALE FOR CPICOR PROJECT SIZE

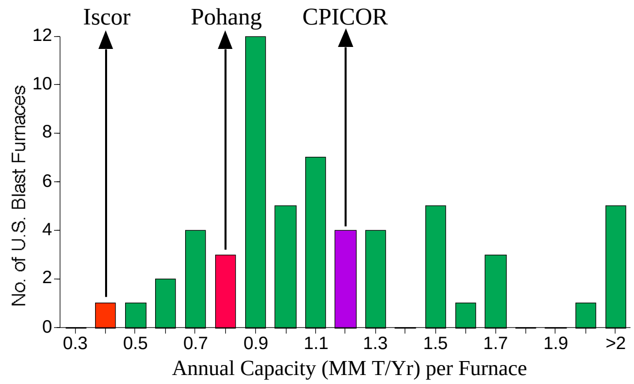
In the U.S., there are currently about 60 blast furnaces, all of which have been operating for more than ten years, with some originally installed up to 90 years ago. **Figure 14** shows the size distribution of these furnaces. As can be seen, the largest operating COREX® facility (~330,000 TPY) is only large enough to replace the smallest of these 60 blast furnaces. The construction of a new facility by POSCO for its Pohang, Korea works will increase demonstrated facility size to 650,000 to 800,000 TPY. The output of this facility is only sufficient to replace about 15% of existing blast furnaces. The proposed demonstration facility size (~1,200,000 TPY) is key to rapid commercialization of COREX®, since it will have the equivalent production rate of a 26 to 28 foot diameter blast furnace. The 3,300 TPD production will be greater than the individual production rates of 75% of domestic blast furnaces. Further scale-up from the demonstration facility by a factor of only 1.5 will produce a unit large enough to exceed the individual output of 90% of existing blast furnaces. Such a factor is well within the range of engineering feasibility. Worldwide, more than 300 blast furnaces with capacity between 0.3 and 1.2 million net tons per year could be replaced in the foreseeable future by COREX®.

CONCLUSION

As evident by the selection of the project by the DOE under Clean Coal V, the CPICOR project has strong support. This technology will provide substantial benefits to the United States coal, steel and power industries while satisfying the key objectives of the Clean Air Act and the National Energy Strategy.

Size Distribution of Domestic Blast Furnaces

FIG. 14



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